AIRPORT PAVEMENT 10-YEAR R&D PROGRAM

ESTIMATED TOTAL PROGRAM COST - $129 MILLION

Submitted by:

Airport Pavement Design R&D Team

Estimated Total Cost - $35 Million

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Estimated Total Cost - $42 Million

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Estimated Total Cost - $52 Million

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ESTIMATED TOTAL PROGRAM COST - $129 MILLION

AIRPORT PAVEMENT 10-YEAR R&D PROGRAM MILESTONE												
Fiscal Year	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Total Cost ($M)**
Airport Pavement Design ($35M)												
Project No. 1: Extending Design Life to 40 Years for Airport Pavements												4.5
Project No. 2: Semi-Accelerated Full-Scale (SAFS) Rigid Pavement Test												5.0
Project No. 3: Validated Reflection Cracking Model for HMA Overlay Design												6.0
Project No. 4: Failure Criteria for Top-Down Cracking in Rigid Airport Pavements												3.0
Project No. 5: FAARFIELD-Based ACN/PCN Methodology												4.5
Project No. 6: New LCCA Integrated Design Procedures												12.0
Airport Pavement Materials ($42M)												
Project No. 1: Advanced Characterization of Paving Materials												22.0
Project No. 2: Use of Additives and Nanoparticles to Improve Performance of Airport Pavement Materials												5.0
Project No. 3: Use of Data and Results From Airport Pavement Instrumentation and Field Testing Studies												15.0
Airport Pavement Evaluation ($52M)												
Project No. 1: Improvements to FAA Airport Pavement Software Programs												14.5
Project No. 2: Development of New Roughness Standards for In-Service Airport Pavement												3.0
Project No. 3: Pavement Surface Profile Data Collection, Processing, and Analysis												11.0
Project No. 4: Nondestructive Pavement Testing												23.5

Airport Pavement Design R&D Team

Design Project No. 1: Extending Design Life to 40 Years for Airport Pavements

Estimated Project Start Date: FY 2012
Estimated Project Completion Date: FY 2016
Estimated Cost for 5 Years: $4.5M

WHY NEEDED:

The Federal Aviation Adminstration (FAA) Office of Airport Safety and Standards has requested that methodologies be developed to extend the expected life of runway pavements at large-hub airports from 20 to 40 years. Such a change will be beneficial both to the Airport Improvement Program (AIP) (which will save reconstruction costs) and to airports, which will experience fewer disruptions associated with major runway reconstruction. This presumes that the additional capital expense in going from a 20-year to a 40-year design will be more than offset by the life cycle cost savings. Other benefits will accrue to airport users and airlines due to fewer construction-related delays, and to the environment, since longer pavement life translates into fewer negative environmental impacts.

Although the current design program, FAARFIELD, does consider nominal design life time frames other than 20 years, this is based on the assumption that serious nonstructural distresses (i.e., those requiring more than normal maintenance) will not be manifest within the design life. While experience has showed that this is a reasonable assumption for a 20-year design, it cannot be extended to 40 years. In fact, there are no procedures in current FAA guidance to design for anything other than structural life. Therefore, designing for a 40-year life expectancy implies that a more general definition of pavement life is needed, one incorporating functional as well as structural requirements.

OUTPUT OF RESEARCH:

The end product will be a methodology for 40-year pavement design combining new pavement performance models, improved material properties and mix designs, innovative maintenance strategies, and life cycle cost analysis (LCCA). The key to the achievement of this goal is a realistic definition of pavement life that considers both structural and functional aspects of pavement failure. Ultimately, the methodology developed in this project will be deployed in a web-based version of the FAARFIELD design program integrated with FAA PAVEAIR. Thus, the execution of this project is closely linked to the follow-on development of LCCA-based design procedures under Design Project No. 6, “New LCCA Integrated Design Procedures.”

RATIONALE:

Extension of airport pavement life from the current 20 years to 40 years is a multifaceted task that involves elements from all three airport pavement research and development (R&D) areas (design, materials, and evaluation), as well as from various airport safety areas. A major element of this research area will be a long-term study of performance data from large- and medium-hub runway pavements in service. This long-term study will include pavement condition index (PCI), as well as performance measures not traditionally considered in pavement structural design, but which affect pavement functional life, such as surface friction, profile roughness, and material degradation over time. These data will be analyzed with a view toward development of new quantitative performance models that can supplement existing structural failure models in FAARFIELD. Runways to be considered in this study fall into two categories: older large- or medium-hub runways in the U.S. for which good construction and long-term maintenance data is available; and new runway projects at large- or medium-hub airports funded through AIP grants. The studied airports will be divided evenly between flexible and rigid construction. A subset of the airport sites will also be visited to collect field data, including PCI, falling weight deflectometer (FWD) data, profiles, groove data, material samples, etc. All the data collected in the course of this project will be stored in a dedicated PAVEAIR database with supplementary fields for all data items. This will not only facilitate efficient analysis of the data and development of performance models, but will also serve as a convenient development platform for FAA PAVEAIR under the Airport Pavement Evaluation R&D area.

Milestone Chart: Extending Design Life to 40 Years for Airport Pavements

Milestone	**FY**										
	12	13	14	15	16	17	18	19	20	21	22
Working definition of pavement life	**x**	**x**									
Dedicated PAVEAIR implementation		**x**									
Selection of 1st group of runways		**x**									
1st year data collection		**x**									
2nd year data collection			**x**								
Preliminary performance models			**x**								
3rd year data collection				**x**							
4th year data collection					**x**						
Final performance models					**x**						

Cost Chart: Extending Design Life to 40 Years for Airport Pavements

Cost by Fiscal Year ($1,000)	12	13	14	15	16	17	18	19	20	21	22	TOTAL
Airport Selection and Database Work	200	200	100	0	0							500
Field Data Collection	500	500	500	500	0							2,000
Laboratory Analysis	100	100	100	200	0							500
Pavement Life Definition	100	0	0	0	100							200
FAA PAVEAIR Dedicated Database Development	200	100	100	100	0							500
Data Analysis/Performance Model Development	0	100	200	200	300							800
Extending Design Life to 40 Years Summary Cost	1,100	1,000	1,000	1,000	400							4,500

Design Project No. 2:
Semi-Accelerated Full-Scale (SAFS) Rigid Pavement Test

Estimated Project Start Date: FY 2016
Estimated Project Completion Date: FY 2020
Estimated Cost for 5 Years: $5M

WHY NEEDED:

To date, the FAA has completed four rigid pavement construction cycles (CC1, CC2, CC4, and CC6) at the National Airport Pavement Test Facility (NAPTF) that provided key full-scale performance data used to update FAARFIELD for new large aircraft. However, these tests, as well as previous tests such as the Multiple-Wheel Heavy Gear Load (MWHGL) tests, were all constrained by relatively short trafficked periods (1 year or less), making their extrapolation to much longer design periods less reliable. As the FAA seeks to extend its current design procedures beyond the current 20 years, full-scale test data at higher traffic levels more representative of 40-year life will be needed. For this reason, a full-scale test on thicker slabs with more realistic joint spacing, to be conducted over 5 years, is proposed for the NAPTF. Because the 5-year period is intermediate between the abbreviated time scale of previous tests and the 20-to-40-year life of real pavements, this test is characterized as semi-accelerated full-scale (SAFS). In addition to providing currently lacking data of fatigue damage at higher traffic levels, the proposed test will correct an important deficiency in current rigid design procedures critical to successful 40-year life extension. Specifically, there is a lack of an adequate model of fatigue damage accumulation in the major phase of rigid pavement life before the appearance of significant cracks. Finally, the proposed test will provide data to evaluate the applicability of the previous full-scale test results to realistic airport pavement slab sizes and thicknesses.

OUTPUT OF RESEARCH:

The end product will be a modified rigid pavement failure model uniting three phases of pavement deterioration: (1) from new construction to fatigue damage initiation at a micro level; (2) from fatigue damage initiation to the first visible cracks; and (3) from first visible crack to the end of the structural life (full failure).

RATIONALE:

In accelerated full-scale traffic tests, one or more of the pavement dimensions (typically layer thickness) is scaled down to achieve failure in a short time frame. All rigid pavement tests to date, including those conducted at the NAPTF in CC1 through CC6, have been accelerated tests, in which the actual trafficking to failure was accomplished in under 1 year. Thus, the results of full-scale tests are concentrated at relatively low coverage levels and have had to be extrapolated to the higher numbers of coverages received by pavements at full thickness. The most recent test series (CC6) succeeded in producing coverages to failure in the 10,000 coverage range, but this appears to be the limit of what can practically be achieved within the current test parameters. Further extrapolation from current data to even higher coverage levels is not recommended. With the extension to a 40-year life for rigid pavements, and the attendant doubling (or more) of expected traffic over the life of affected runways, new semi-accelerated tests are needed that will produce reliable failure data in the 100,000 coverage range.

An SAFS rigid pavement test is proposed for the NAPTF. This test would last 5 years and would involve pavement slabs in the 15- to 16-inch range, more typical of actual pavement slabs at large-hub airports. In line with the current, empirical FAA standards governing thickness-to-joint spacing ratio, the greater slab thickness would also allow more realistic slab sizes in the 18- to 20-ft. range. The unavoidable tradeoff for having all physical scales agree with the field is that the time scale for testing is longer. This means that for the first several years the pavement would not be expected to exhibit visual distress (surface cracks). However, this also presents an opportunity to monitor in detail and collect data on the initial phase of fatigue damage (prior to the first through cracks). This can be accomplished through a variety of nondestructive monitoring techniques (e.g., Ground Penetrating Radar (GPR) and magnetic resonance imaging (MRI)) with which the FAA has already gained experience, as well as advanced embedded sensors, such as the use of fiber-optic strands to detect initial cracks within the concrete matrix. Understanding and modeling damage accumulation in this first phase of fatigue damage is a weak point in the current procedures that will become more important with the extension of design life to 40 years. It is anticipated that full-scale testing of the SAFS slabs will be performed in conjunction with concrete material fatigue testing to be performed under the "Advanced Characterization of Materials" project within the Pavement Materials R&D area. This will lead to better modeling of fatigue damage from existing laboratory tests.

The time horizon for this project is 5 years. However, it is not contemplated that the NAPTF test vehicle would be dedicated exclusively for that entire period of time. Rather, trafficking of the SAFS test items would be limited to part of the year, so that the vehicle will be available for other projects or for maintenance. During periods of no traffic, activities such as data analysis, nondestructive testing (NDT), etc., would be performed. Strategies should also be considered that would reduce overall trafficking time and hence demand for the test vehicle. Such strategies might include reducing the overall length of the test item (say, from five slabs to three), or possibly modifying the current wander pattern consisting of nine tracks by eliminating some tracks, provided it can be shown through analysis that certain gear offsets contribute insignificantly to fatigue damage.

Milestone Chart: SAFS Rigid Pavement Test

Milestone	FY 12	13	14	15	16	17	18	19	20	21	22
Test item construction & sensor installation					x						
1st year traffic					x						
1st year data collection					x						
2nd year traffic						x					
2nd year data collection						x					
3rd year traffic							x				
3rd year data collection							x				
4th year traffic								x			
4th year data collection								x			
5th year traffic									x		
Posttraffic testing									x		
3-phase rigid failure model									x		

Cost Chart: Semi-Accelerated Full-Scale (SAFS) Rigid Pavement Test

Semi-Accelerated Full-Scale (SAFS) Rigid Pavement Test												
Cost by Fiscal Year ($1,000)	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**TOTAL**
Test Item Construction and Instrumentation					1,500	0	0	0	0			1,500
Data Collection and Monitoring					500	250	250	250	250			1,500
Posttraffic Testing					0	0	0	0	500			500
Data Analysis and Model Development					250	250	250	350	400			1,500
Semi-Accelerated Full-Scale (SAFS) Rigid Pavement Test Summary Cost					2,250	500	500	600	1,150			5,000

Design Project No. 3: Validated Reflection Cracking Model for HMA Overlay Design

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2018
Estimated Cost for 6 Years: $6M

WHY NEEDED:

The FAA currently lacks a usable model of reflection cracking for hot-mix asphalt (HMA) overlay design. FAARFIELD 1.3 does not consider this important distress mode. The goal of this project is to produce a reliable life prediction model for overlays based on reflection crack growth. Successful completion of this project is critical to reaching the goal of 40-year pavement life extension for rigid pavements, because many LCCA-based designs will have to incorporate future HMA overlays as an alternative to increasing initial slab thickness. Therefore, a reliable life prediction model for overlays incorporating reflection cracking is essential.

OUTPUT OF RESEARCH:

The expected product is a set of fully validated equations (the failure model) that can be directly implemented in the overlay design procedure in all future versions of FAARFIELD. The failure model will relate the required thickness of asphalt overlay to several input variables, including projected traffic, climatic data (temperature cycles), and the condition of the existing pavement.

RATIONALE:

Many LCCA-based strategies for 40-year life design will anticipate that one or more flexible overlays of rigid pavements will be placed over the course of the pavement life. Extending pavement life to 40 years obviously depends on having a reliable and validated overlay model incorporating the most prominent distress type in such overlays, i.e., reflection cracking. Currently, this type of model does not exist. The LEDFAA overlay design model incorporated a crude estimate of reflection crack growth (1 year per inch of thickness), but this was removed in FAARFIELD because it was found to produce unsatisfactory or illogical designs. The current FAARFIELD model does not explicitly consider reflection cracking at all, which is likewise unacceptable.

Development of a new, validated design model incorporating reflection cracking will rely on three elements: (1) data from the indoor NAPTF reflection cracking rig, (2) the generalized finite element model (GFEM) previously developed by the Center of Excellence for Airport Technology (CEAT) at the University of Illinois Urbana-Champaign, and (3) outdoor tests on asphalt-on-rigid overlay structures conducted using the new FAA heavy vehicle simulator for airport pavements (HVS-A). It is expected that such a design model will have to employ environmental inputs as a driver to the reflection cracking model. Essentially, reflection crack propagation rates can be observed under controlled conditions with the reflection cracking rig mechanically simulating the temperature cycles occurring in nature. Failure in this case is considered to be the appearance of cracks on the HMA surface that propagate from (i.e., are “reflected” from) joints in the overlaid concrete. Using the GFEM model, these observations can be translated into a provisional failure model for design. The provisional failure model will then be subject to further outdoor testing using the HVS-A. With the HVS-A, it is possible to compare trafficked and nontrafficked overlays subject to the same uncontrolled (but predictable) environmental cycling to (1) validate the failure model under conditions similar to field conditions, and (2) determine the extent to which reflection cracking is also a function of traffic, not just time.

Milestone Chart: Validated Reflection Cracking Model for HMA Overlay Design

Milestone	FY										
	12	13	14	15	16	17	18	19	20	21	22
Phase 2 reflection cracking rig test at NAPTF		x									
GEFM model results				x							
Phase 3 & 4 reflection cracking rig test				x		x					
Adjust GEFM model					x		x				
Provisional failure model					x						
Begin HVS-A test			x								
Interim HVS-A data				x	x	x					
Complete HVS-A test (4 years)							x				
Final failure model in FAARFIELD							x				

Cost Chart: Validated Reflection Cracking Model for HMA Overlay Design

Cost by Fiscal Year ($1,000)	12	13	14	15	16	17	18	19	20	21	22	TOTAL
Reflection Cracking Rig Overlay Rebuild and Test		400	0	400	0	400	0					1,200
GEFM Modeling (University grant)		100	100	100	100	100	100					600
HVS-A Test Sections Construction and Instrumentation		500	950	0	0	0	0					1,450
HVS-A Operation and Data Collection		0	0	250	250	250	250					1,00
Data Analysis and Model Development		0	0.15	400	400	0.40	400					1,750
Validated Reflection Cracking Model for HMA Overlay Design Summary Cost		1,000	1,200	1,150	750	1,115	750					6,000

Design Project No. 4:
Failure Criteria for Top-Down Cracking in Rigid Airport Pavements

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2018
Estimated Cost for 6 Years: $3.0M

WHY NEEDED:

Top-down cracks in rigid pavements arise from various combinations of slab curling, residual concrete stresses and complex gear loads. Top-down cracks can lead to early failures of individual slabs or entire pavements. However, the current FAARFIELD thickness design procedure does not consider this failure mode. Instead, current FAA standards attempt to limit top-down cracks through joint spacing limitations based on experience and rules-of-thumb. As climatic conditions vary widely throughout the U.S., this empirical approach may be ineffective in some cases and result in unnecessary costs in others. One factor that is currently unknown is the role played by the concrete design strength, which may be considerably lower than the actual in-place strength. As the FAA moves toward allowing higher concrete strength in pavement design, it needs to be understood how the resulting thinner slabs may affect the risk of top-down cracking.

OUTPUT OF RESEARCH:

The result of this project will be rational criteria for determining the effect of the top-down cracking mode on rigid thickness design in FAARFIELD. The output consists of two parts, as follows:

1. Rational criteria for determining whether or not the top-down cracking mode needs to be considered in thickness design, and if so, under what conditions (the “whether” criterion).

2. A mathematical failure model to apply in cases where top-down cracking must be considered (the “how” criterion). This failure model will presumably require technical inputs in addition to the gear load stresses, such as climatic conditions (temperature and moisture), joint spacing, and some estimate of residual stresses. These inputs will have to be determined as part of the project.

RATIONALE:

The current FAA rigid pavement thickness design considers only the critical tensile stress at the bottom of a slab. However, studies both at the NAPTF and at Airbus test facilities in Toulouse, France, found that cracks often initiated from the top of the slab, and that top-down cracks occurred earlier than bottom-up cracks in most tests. Furthermore, full-scale testing at the NAPTF has demonstrated that top-down cracks progress from initiation to full depth much more quickly than bottom-up cracks. Contributing factors to top-down cracks are a high-moisture gradient and the temperature gradient, in combination with complex aircraft gear configurations. The mechanism of top-down cracking cannot be explained rationally using load-induced stress alone because measured maximum tensile strains near the slab bottom are generally higher than those near the slab surface. (Load-induced stresses are assumed to be proportional to strain.) It must, therefore, be considered that the total stress operating on the concrete slab, i.e., the stress that leads to the rupture, is the sum of the load-related stress and the residual stress. The residual stress can be understood as the stress that exists prior to any load being applied. Residual stresses can be separated into two broad cases: (1) internal stresses, which build up during curing and then change slowly over time, and (2) stresses induced in a layer close to the surface of the slab by microclimatic changes occurring just above the slab. The latter can change rapidly as the microclimate (rain, sun, wind, etc.) changes. Residual stresses may be a significant proportion of applied stress, and the total tensile stress at the top of the slab may become critical under certain circumstances. For example, small airports sometimes require accommodating a limited number of operations of an airplane heavier than the pavement was designed to support. For these thinner concrete slabs, the risk of top-down cracking becomes a major concern for allowing or rejecting the overload operations. In addition, field survey data for medium and large airports suggests that top-down cracks have to be considered for terminal pavements where heavy airplanes irregularly move near the slab corners.

Is it necessary to consider the top-down cracking potential in all rigid pavement designs, or only for well-defined, special circumstances such as those described above? Certainly, the fact that top-down cracks have been observed in all full-scale tests to date supports changing the standard rigid design to include a top-down cracking mode. However, the question still remains: Do those test results truly reflect rigid pavement performance and behavior in the field? Both field data and numerical analysis are needed to provide the necessary data for determining whether, when and how to consider top-down cracking risks in design.

An innovative means of measuring the residual stress has been developed recently at the NAPTF. The test procedures have been investigated, improved, and evaluated through a number of FAA-sponsored research projects. The next step is to use this test to determine the expected range of residual stresses under different environmental conditions so that reasonable values of total stress can be incorporated in expanded rigid design procedures. In addition, field assessments will be made of the occurrence of top-down cracking under in-service loading. Information on the relative occurrence of top-down cracks in service will come from analysis of construction and performance data collected from new and recent AIP airports under the recently initiated Extended Pavement Life study for large- and mid-sized hubs.

Parallel to the experimental studies, numerical analysis is required to investigate how environmental conditions combine with load to affect critical responses in rigid pavements. Previous three-dimensional (3D) finite element (FE) studies by the FAA Airport Technology R&D Branch involving multiple-jointed slabs and complex gear configurations established critical combinations of gear positions and slab curling for top-down cracking. The missing element in these numerical models is the total stress under static and moving loads, which can explain the dominance of top-down cracking in cases where slab curling is insignificant or controlled. Therefore, the existing FEAFAA program will be modified to add the ability to compute total stresses under moving gear loads under various conditions and assumptions.

Milestone Chart: Failure Criteria for Top-Down Cracking in Rigid Airport Pavements

Milestone	FY										
	12	13	14	15	16	17	18	19	20	21	22
40-Year Life Field Data Reports		x	x	x	x	x					
Modification of FEAFAA to compute total slab stress for multiple slabs			x								
Analysis of top-down cracking in 40-year life pavements				x							
Field determination of residual stresses under different conditions			x	x	x						
Propose criteria for when top-down cracking must be considered in design					x						
Identify all inputs and outputs for top-down failure model					x						
Trial implementation of top-down failure model in FAARFIELD						x					
Evaluate failure criteria							x				

Cost Chart: Failure Criteria for Top-Down Cracking in Rigid Airport Pavements

Cost by Fiscal Year ($1,000)	12	13	14	15	16	17	18	19	20	21	22	TOTAL
Analysis of 40-Year Life Rigid Pavement Field Data reports		200	200	200	200	200	0					1,000
FEAFAA Program Modifications		100	100	0	0	0	0					200
Residual Stress Field Determination		200	200	100	100	0	0					500
Data Analysis and Top-Down Failure Model Development		0	100	200	200	200	250					950
Trial Implementation of Criteria in FAARFIELD		0	0	0	0	100	250					350
Criteria for Top-Down Cracking in Rigid Airport Pavements Summary Cost		500	500	500	500	500	500					3,000

Design Project No. 5: FAARFIELD-Based ACN/PCN Methodology

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2021
Estimated Cost for 9 Years: $4.5M

WHY NEEDED:

The current Aircraft Classification Number–Pavement Classification Number (ACN-PCN) reporting system in use throughout the world is of great value to both airports and aircraft manufacturers, largely because of its simplicity of concept. The FAA has long been in the forefront of the development of the ACN-PCN method, and it is important for the FAA to maintain its international leadership role. The consensus among civil aviation authorities (CAAs), aircraft manufacturers and other stakeholders in the ACN-PCN system is that the existing California Bearing Ratio (CBR)-based PCN methodology is outdated and an improved system is desirable. The FAA's decision to discontinue using the CBR method for pavement design in favor of the FAARFIELD computer program highlighted the need to develop a new strength-reporting procedure based on layered elastic analysis. Therefore, the key element of this task is the development of an alternative method for calculation of the (PCN that makes use of the FAARFIELD software. Once adopted, this method would have significant advantages over the current standard procedures, as follows:

- Eliminating incompatibilities between pavement thickness design and pavement strength reporting requirements. Currently, it is relatively common to encounter situations where strictly applying pavement strength reporting requirements would lead to unnecessary operating weight restrictions on airplanes that the pavement was designed to support. This contradiction encourages designers to overconservatively "design to the PCN" using COMFAA even though the ACN-PCN procedures are explicitly not intended to be used as a design method. These problems can be reduced through adjustments to the failure models, etc., but never completely eliminated due to the fundamental differences between the layered elastic FAARFIELD model on the one hand, and the current CBR- and Westergaard-based PCN calculation procedures on the other.

- Allowing more natural integration of FAA pavement strength reporting functions with FAARFIELD in the context of an overall program integration scheme centered on FAA PAVEAIR.

- Lessening, if possible, the current method's dependence on the choice of the critical aircraft. Ideally, the PCN number should be a characteristic of the pavement structure and should not depend excessively on the specific aircraft type used to compute it.

OUTPUT OF RESEARCH:

The major product will take the form of a software module within FAARFIELD implementing the new method. Outputs may also include written guidance on how to report PCN using the new procedure in the form of a draft advisory circular.

RATIONALE:

The project will be accomplished through several subtasks. Subtasks a through d below cover just the development of a FAARFIELD-based PCN methodology, which will be applied in conjunction with current International Civil Aviation Organization (ICAO) ACN procedures. This portion is expected to take 3 years, with an additional 1 year for software implementation and testing. The full project, extending to a re-evaluation of the current CBR-based ACN methodology and the development of a new rational procedure for evaluating potential overloads (subtasks e and f below), is expected to take 9 years.

a. **Implementation of a fully automated procedure in FAARFIELD for identifying the critical aircraft for PCN calculations and computing the maximum allowable gross weight for the identified critical aircraft.** (1 year)

b. **Development of the Parameters of a new PCN Methodology.**
   This step is not simply technical but will involve the input of numerous ACN-PCN stakeholders. Some issues to be decided include the following: Will PCN continue to be computer based on the traffic used in FAARFIELD thickness design? How should FAARFIELD handle thick HMA overlays on concrete bases or other pavements that would be classed as "composite" according to the ICAO Aerodrome Design Manual? How should traffic levels be considered in the case of 40-year pavement life, in particular, if the 40-year life assumes there will be overlays or other major structural interventions (beyond normal maintenance) as part of LCCA? As part of this task, test cases representing "real-world" airport pavements will be obtained from members of the PCN Working Group for evaluating different PCN methodologies. (2 years)

c. **Improved Characterization of Subgrade Soils in Layered Elastic Procedures.**
   Currently, FAARFIELD employs a simple, linear equivalence between the CBR number and the elastic modulus (E) of a soil. This implies that the ratio of soil strength to elastic modulus is the same for all soil types, which is not a realistic assumption based on current knowledge of soil mechanical behavior. As part of planned research in the Airport Pavement Materials area, the FAA will perform comprehensive testing of a selection of airport subgrade materials to develop improved criteria for subgrade characterization in FAARFIELD. In parallel with this testing effort, an elasto-plastic FE model simulating the field CBR test will identify those soil test properties in addition to modulus that strongly influence CBR. Implementation of these new criteria in a FAARFIELD-based PCN procedure should result in more reliable reporting of pavement strength. (3 years, in parallel with subtasks a and b)

d. **Software Implementation and Testing.**
   Software implementation will take the form of a separate PCN module within FAARFIELD. The function of this module will be much the same as the current PCN

routine in COMFAA 3.0, except that cumulative damage factor (CDF), allowable load, and other computations will be performed internally using the layered elastic structural models in FAARFIELD. Specific details of the PCN computation will follow the parameters determined in subtask b.

e. **Compare the Current ICAO Method of Determining ACN for Critical Aircraft With a Set of Alternative ACN Procedures Based on FAARFIELD.**
This entails determining a standard structure or set of standard structures for FAARFIELD ACN computations, as well as other parameters of an alternative ACN method, such as How should the traffic levels used for PCN be reconciled with the fixed traffic levels assumed as part of ACN? More broadly, should ACN continue to be based on an arbitrary 10,000 coverages or are other numbers more suitable to extended pavement life? (2 years)

f. **Develop Rational Overload Procedures.**
Using the developed PCN procedure, extend the method to relate occasional overloads of particular aircraft to reductions in life and associated life cycle costs. This step could call on FAARFIELD and PAVEAIR to perform specific computational tasks within an integrated program architecture. (4 years)

Milestone Chart: FAARFIELD-Based ACN/PCN Methodology

Milestone	FY										
	12	13	14	15	16	17	18	19	20	21	22
Procedure to identify critical PCN aircraft in FAARFIELD			**x**								
Obtain PCN case studies			**x**								
Update FE model of CBR test				**x**							
Define parameters of new PCN methodology				**x**							
Identify key soil test properties influencing CBR					**x**						
Implement & test new PCN module in FAARFIELD program						**x**	**x**				
FAARFIELD-based ACN Comparisons								**x**	**x**		
New Overload Procedures										**x**	

Cost Chart: FAARFIELD-Based ACN/PCN Methodology

Cost by Fiscal Year ($1,000)	12	13	14	15	16	17	18	19	20	21	22	TOTAL
Implementation of PCN Critical Aircraft Functions in FAARFIELD		250	250	0	0	0	0	0	0	0		250
Update FE Model of CBR Test		250	250	0	0	0	0	0	0	0		250
Analyze Case Studies for Method Development		0	0	250	250	250	0	0	0	0		750
Implement New PCN Module in FAARFIELD		0	0	250	250	250	0	0	0	0		750
Perform FAARFIELD-based ACN Comparisons		0	0	0	0	0	250	250	0	0		250
New Overload Procedures		0	0	0	0	0	250	250	250	250		1,500
FAARFIELD-Based ACN/PCN Methodology Summary Cost		250	250	250	250	250	250	250	250	250		4,500

Design Project No. 6: New LCCA Integrated Design Procedures

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2022
Estimated Cost for 10 Years: $12M

WHY NEEDED:

Airport pavement design procedures must be updated to support integration with a true life cycle cost-based approach. The goal of a life cycle cost approach is to facilitate a rational selection of the optimal design from among several competing options. Current design procedures treat the structural design problem as independent of long-term management strategies, with Life Cycle Cost Analysis (LCCA) considered after the fact if at all. Cost savings will result from optimizing pavement designs to give the lowest life cycle cost over either a 20- or 40-year evaluation period. It is estimated that, once implemented, standardized LCCA procedures could save the AIP up to $2.1 billion over 20 years. This project will mesh with several planned tasks under the Airport Pavement Evaluation R&D area, specifically: (1) the LCCA data repository, (2) development of LCCA procedures and standards for the FAA, and (3) integration of the design and evaluation software with FAA PAVEAIR as a web-based application.

OUTPUT OF RESEARCH:

The output of this project will be a user-friendly design procedure, integrated with other FAA programs, generating 20- or 40-year airport pavement designs in accordance with new FAA LCCA procedures that will be developed under a parallel project. Unlike the current FAARFIELD program, which is a stand-alone software application running on personal computers (PC), the new procedures will be seamlessly integrated into the web-based FAA PAVEAIR environment, and thus be able to access cost data, performance models, and other design inputs from the online FAA PAVEAIR data repository.

RATIONALE:

Increasing use and popularity of the life cycle approach to selection of airport pavement type requires integration of pavement design procedures with new LCCA procedures. The AIP Handbook, paragraph 508, states that "life-cycle costs shall be considered in AIP procurement where specified in bidding documents." However, there is a lack of standards on what constitutes appropriate consideration of LCCA, and what specific costs should be included. Currently, FAA technical guidance on LCCA procedures is general and extremely limited, consisting only of a 4-page appendix to Advisory Circular (AC) 150/5320-6E, which suggests that the FAA approaches LCCA as a minor afterthought to the technical design of pavements.

Particularly with the advent of a 40-year life design for certain categories of airport pavements, there is a need to consider more than just the "up front" construction cost. Essentially, there is a need for a strategy of informed tradeoffs. Initial costs must be balanced against the costs of programmed maintenance, planned future rehabilitation, and other future factors, ideally resulting in the optimal design choice. Put another way, a structural design satisfying a 40-year life requirement may give satisfactory performance, but it is not necessarily better (from a life cycle cost point of view) than a design for a structural life of less than 40 years but accompanied by a strategy of rehabilitation.

Implementation of LCCA-based design procedures will be accomplished through the following subtasks.

a. **Develop Framework for Integration of FAARFIELD Design With LCCA Model.** The first step in the implementation of LCCA-based design procedures is to develop a workable conceptual framework for merging the thickness design and LCCA procedures. Assuming that FAA PAVEAIR is the primary driver of the integrated procedure (Figure 1), one of the main goals of this task is to determine how FAARFIELD will fit into the overall operational scheme. For example, what should be the entry points for FAARFIELD in the LCCA module within FAA PAVEAIR? The current LCCA module (AirCost) is based on several spreadsheet "tabs." The most obvious point of interaction with FAARFIELD is the "Create Alternatives" tab, which defines pay items for each considered alternative. Clearly, many of these pay items correspond to layers in FAARFIELD design, and their quantities can, therefore, be determined by standard thickness design methods. However, other links may need to be set up as well (such as the analysis period). This task should be performed in conjunction with the associated tasks for developing LCCA procedures and integrating design and evaluation software in the Airport Pavement Evaluation R&D area.

b. **Modification of HMA-on-Flexible Overlay Design Procedures for 40-Year Life.** The FAA's plan for implementing a 40-year pavement life contemplates that existing design procedures will be modified to account for material degradation over time, as well as expected surface replacements or overlays. While the base structure should have a structural life of either 20 or 40 years, depending on the design requirements, the upper or surface layers are expected to have a functional life that is considerably less than the design period. Therefore, HMA-on-flexible overlay design will become one element within an expanded new flexible pavement design procedure based on the LCCA approach. There are clear similarities between this approach (i.e., successive mill-and-overlay operations at planned intervals to achieve a 40-year structural and functional life) and the concept of perpetual pavement. The latter, however, assumes that the supporting layers will be fully protected by the HMA surface layers, hence, free from structural damage for an indefinite period, which may or may not be the case for heavily loaded airport pavements. Development of the validated design model for HMA-on-flexible overlay will, therefore, need to consider certain elements that are missing from the current overlay design model.

    i. Deterioration of structural layers under traffic for 40 years. The current model assumes all pavement materials have "new" properties regardless of when they are overlaid and, therefore, does not consider the concept of used life analogous to overlays on rigid pavement. The possibility of adjustments to the fatigue model for older HMA layers receiving overlays should be considered.

ii. Degradation of material properties under environmental and climatic influences for 40 years. This is expected to occur at different rates, depending on geographic location.

iii. Possible existence of an endurance (fatigue) limit for HMA and base materials.

Validation of the modified overlay design model will rely on several sources of data: (1) planned NAPTF full-scale testing (CC7) incorporating the "perpetual pavement" concept; (1) test data on new flexible pavement and HMA-on-flexible overlay pavements using the new FAA HVS-A for airport pavements; (3) construction and performance data collected for new and recent AIP-funded runway pavements under the Extended Pavement Life study. One of the major outputs from the Extended Pavement Life study will be new airport pavement performance models applicable to various measures of pavement performance (e.g., surface rutting, groove deterioration, etc.) that typically drive a decision to overlay or replace the pavement. These performance models will be implemented in the new design procedure along with the traditional structural failure models. NAPTF tests will be designed to test the concept of an endurance limit for various layers of flexible pavements and to gain additional data on the subgrade damage and structural layer deterioration models. HVS-A tests will be designed specifically to provide validation data for the "ratio of dissipated energy change" (RDEC) model previously developed by CEAT for asphalt mixture fatigue cracking.

c. **Integration of HMA-on-Flexible Design Procedures with LCCA Model.**
The expanded HMA-on-flexible overlay design procedure developed under task b provides a ready framework for performing life cycle cost-based designs for any given design period up to 40 years. Essentially, overlay strategies at different time intervals can be compared, considering variables such as available resources and expected performance. Using the LCCA procedures developed under an Airport Pavement Evaluation task, the life cycle costs of various overlay strategies can be analyzed and compared in a standardized manner. The final strategy selected is the one yielding the optimal economic benefit over the course of the appropriate evaluation period, whether 20 or 40 years.

d. **Modification of Rigid Pavement Failure Criteria for 40-Year Life.**
Tasks b and c apply to flexible (asphalt) pavements. The rigid (concrete) pavement thickness design procedure implemented in FAARFIELD is based on the Structural Condition Index (SCI) concept. Although the current failure criterion is for an SCI of 80 (where 100 is the SCI of a new pavement), in practice, rigid pavements are frequently operated beyond this level of structural deterioration, but with an expected increase in frequency of maintenance activities and, perhaps, with changes in the type of maintenance or rehabilitation. Carrying this strategy one step further, the design procedure could be modified to allow other SCI values to be specified for failure and, when combined with different maintenance strategies, incorporated in the LCCA to find an optimum "failure SCI" yielding the lowest life cycle cost.

e. **Define Limitations on User Input.**
In developing a practical design standard, it is always necessary to establish which of the many input variables are fixed and which can be set by the designer. In the case of user

input, it may be further necessary to define allowable ranges or limits for particular variables. This was done with respect to material properties in the current FAARFIELD design program. In a future LCCA-linked version of FAARFIELD, it will be similarly necessary to limit user selection of economic variables, such as discount rates and unit costs. This is necessary to provide a uniform basis on which to evaluate designs that may be eligible for AIP funding and to limit the ability of users requesting AIP funds to manipulate the LCCA procedure in order to favor a predetermined alternative. Standards for LCCA developed under the appropriate task within the Airport Pavement Evaluation R&D area will be implemented in the design procedure.

f. **Reliability Statement for FAA Design Procedures.**
The reliability of a system is a statistical measure of its ability to perform its intended function over its intended service life, expressed as a percent. For pavement systems, that life has traditionally been 20 years. Previous research based on limited available performance data of AIP airports indicated that the existing procedures are generally "reliable" in the sense of mostly meeting or exceeding the 20-year standard. However, in the past, there was not sufficient data to quantify reliability statistically. By statistically analyzing design and long-term performance data for large- and medium-hub runway projects collected under the Extended Pavement Life study, as well as other available performance data for AIP-funded pavements in the FAA PAVEAIR data repository, it will be possible to assign reliability values to the FAA design procedures for various new and overlay pavement types.

g. **Integration as Web-Based Application.**
This step should be performed in close coordination with the relevant project in the Airport Pavement Evaluation R&D area, following all procedures established for integration with FAA PAVEAIR. One issue that will have to be addressed is the best means of migrating computationally intensive parts of the current (stand-alone) FAARFIELD program to a web-based platform. This especially applies to the Fortran FE subprograms NIKE3D and Ingrid, which have significant run time and resource requirements when run on local PCs. By shifting the FE operations from the client computer to the "cloud" (i.e., allowing computations to be performed on a remote server), and ensuring that adequate processing resources are available on the server side, it should be possible to improve the efficiency of rigid pavement design computations significantly.

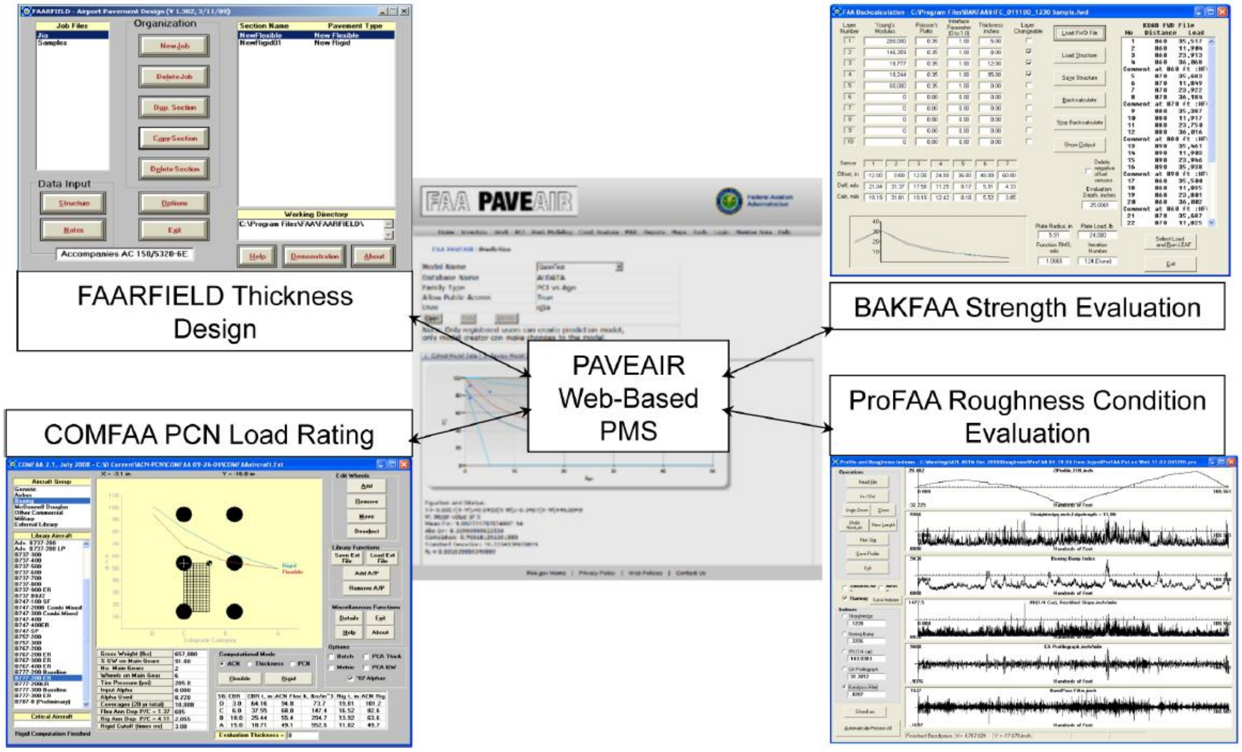

Figure 1. FAA PAVEAIR Integration (from *Airport Technology Research Plan … for the NextGen Decade*, January 2012)

Estimate of Annual Cost Savings from Implementing LCCA-Based Design Procedures

The savings to the AIP over 20 years is estimated as follows.

From the 2011 AIP Grant Summary, total AIP grant funds awarded in 2011 were $3.48 billion. This includes all AIP grants, not just those for pavement capital projects. Assume, very crudely, that the net present value (NPV) of all airport pavement capital projects for 2011 was $3.0 billion.

Further assume that LCCA would save 5% of the NPV on average if implemented as a routine part of the design procedure. Available LCCA guidelines suggest 10% as the threshold to determine when alternate bidding is allowed (i.e., the difference in NPV between the higher- and lower-cost alternatives is 10% or less), suggesting that 10% is a reasonably conservative “middle value.” On the other hand, if LCCA is not mandated, the lowest-cost alternative would still be selected perhaps 50% of the time. Therefore, an average 5% cost savings in NPV seems reasonable.

NPV of savings = 0.05 × $3.0B = $150 million

This is the present value of the savings over the pavement life (20 or 40 years), considering all applicable factors such as initial costs, maintenance costs, user costs, and salvage value. Since the lowest life cycle cost does not necessarily correspond to the lowest initial cost option, the value $150 million does not represent initial cost savings. To get an idea of the annualized cost savings, multiply the present worth of savings over the life by a capital recovery factor (CRF) assuming that i = 3% (interest rate) and n = 20 years:

$$CRF = \frac{0.03(1.03)^{20}}{(1.03)^{20} - 1} = 0.0672$$

Equivalent Uniform Annual Cost (savings) = 0.0672 × $150M ≈ $10 million annually. While $10 million per year might not sound like a great deal of money in the context of the AIP budget, it does add up. In the first year, the savings is $10 million. In the second year, it would be $10M + $10M = $20M (because of another set of AIP grants), in the third year, $10M + $10M + $10M = $30M, and so forth. Therefore, over 20 years of AIP grants, this translates to a cumulative savings of approximately $2.1 billion.

Milestone Chart: New LCCA Integrated Design Procedures

Milestone	**FY**										
	12	13	14	15	16	17	18	19	20	21	22
Develop Framework for Integration		**x**									
First 40-Year Life Field Data Reports		**x**									
Complete CC7 Trafficking		**x**									
Acquire HVS-A Test Data			**x**	**x**							
Modified Rigid Failure Criteria					**x**						
Modified HMA-on-Flexible Overlay Design Procedures						**x**					
Analyze Extended Pavement Life Data		**x**	**x**	**x**	**x**	**x**	**x**				
Define Limitations on User Input							**x**				
Final LCCA Procedures (Evaluation R&D Area)								**x**			
Reliability Statement									**x**		
Integrate Design and Evaluation Software (Evaluation R&D Area)									**x**	**x**	
Validated Design Procedures in FAA PAVEAIR											**x**

Cost Chart: New LCCA Integrated Design Procedures

Cost by Fiscal Year ($1,000)	12	13	14	15	16	17	18	19	20	21	22	TOTAL
Develop Framework for Integration		500	0	0	0	0	0	0	0	0	0	500
Analyze Extended Pavement Life Data		500	500	500	500	500	200	0.1	0	0	0	2,800
Analyze NAPTF CC7 Test Items		200	500	500	200	0	0	0	0	0	0	1,400
HVS-A Overlay Test		0	200	200	200	200	0	0	0	0	0	800
Develop Pavement Performance Models		0	0	0	200	300	500	400	200	0	0	1,600
Integrate Design and LCCA Procedures in PAVEAIR Framework		0	0	0	100	200	500	500	500	500	500	2,800
Define User Inputs and Ranges		0	0	0	0	0	0	200	200	200	200	800
Reliability Statement		0	0	0	0	0	0	0	100	100	100	300
Integrate/Test Web-Based Application		0	0	0	0	0	0	0	200	400	400	1,000
New LCCA Integrated Design Procedures Summary Cost		1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	12,000

PAVEMENT DESIGN R&D TEAM SUMMARY

Consequences of not doing R&D in Pavement Design:

1. Failure to achieve the goal of reliable 40-year life for airport pavements.
2. Higher life cycle costs because of failure to integrate with LCCA.
3. Higher construction costs from failure to incorporate results of full-scale tests in design procedures.
4. More lost opportunity costs because of service interruptions for unplanned interventions.

Benefits:

1. Cost savings of up to $2.1 billion over 20 years from the addition of LCCA to the pavement thickness design process and coupling of the design procedure to new LCCA standards.
2. Cost savings from improved modeling and pavement performance prediction, including much more reliable overlay life prediction.
3. "Green" benefits through longer-lived pavements requiring fewer construction interventions.
4. Reduced design conservatism.
5. Less down time for unprogrammed repairs and rehabilitations of airport pavements.

Airport Pavement Design R&D Projects:
Estimated Total Cost - $35 Million

Airport Pavement Materials R&D Team

Materials Project No. 1: Advanced Characterization of Paving Materials

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2021
Estimated Cost for 8Years: $22M

WHY NEEDED:

In the current FAA flexible pavement thickness design procedure, CBR of subgrade is the only material property input required. Other inputs for material properties are fixed and cannot be changed by the user. FAA advisory circulars lack guidance on the use of sustainable, environmentally friendly, recycled, and newer materials such as stone matrix asphalt (SMA), warm-mix asphalt (WMA), etc. (Limited knowledge is available on the effect of high tire pressures and heavy gear loads on pavement material performance under full-scale loading.) The cost of using better quality material to improve pavement performance (life) cannot be justified using current guidance. Advances in pavement material testing techniques and knowledge gained in material behavior and characterization over the years is not used in the FAA pavement thickness design procedure. Providing realistic material properties (such as HMA modulus at design temperatures, resilient modulus of soils, and unbound materials) as inputs will improve the pavement thickness design procedure and pavement life predictions.

OUTPUT OF RESEARCH:

The output from the materials research program will be updated FAA standards and specifications and guidelines for use of conventional, sustainable, eco-friendly materials for airport pavements. Guidelines for material input properties such as resilient modulus, shear strength, and other material properties for use in airport pavement thickness design procedure, FAARFIELD. The research results will be used to develop paving materials property database for use in PAVEAIR and life cycle cost analyses. (This research will result in increased use of environmentally friendly (greener) materials, increased use of locally available materials (materials modified with admixtures), quantifying material properties, improved/optimized pavement thickness designs, and more durable, longer-life airport pavements.) This will help save money through lower costs of initial construction, maintenance, and repairs as well as through lower user delay costs, conserve airport development funds, reduced downtime of runways, and improve ride quality and safety.

RATIONAL:

An airport pavement is a complex engineering structure. Pavement analysis and design involves the interaction of four equally important components (Figure 2): (1) the subgrade (naturally occurring soil), (2) the paving materials (surface, base, and subbase), (3) the characteristics of applied loads, and (4) climate. Failure in any one of the pavement structure components can result in the failure of the complete structure.

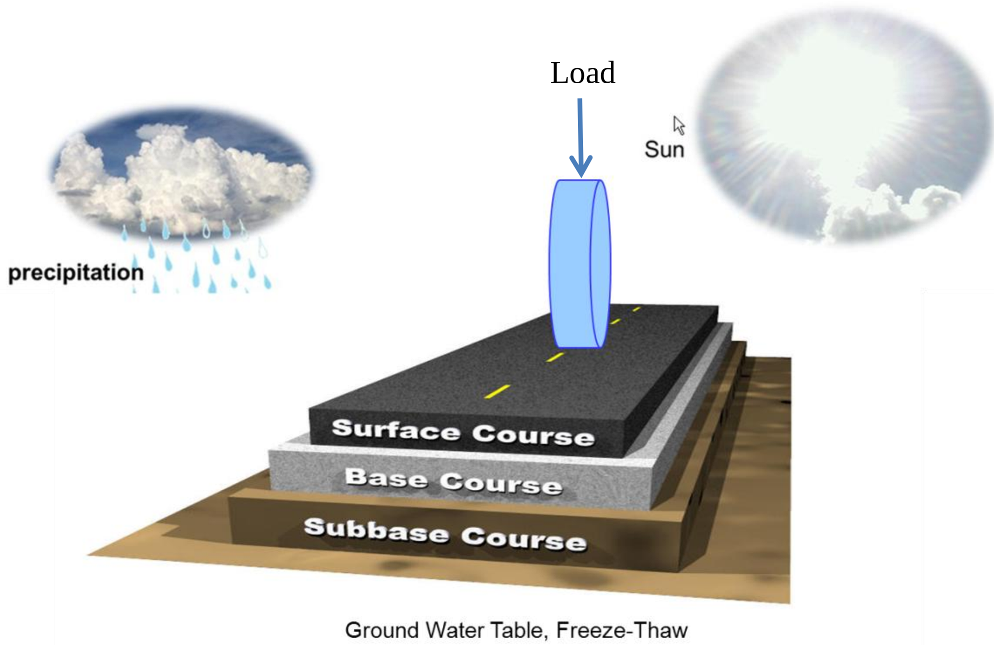

Figure 2. Airport Pavement System

Failure in pavements is not a phenomenon of chance, but a phenomenon that has a definite mechanical cause. When the pavement is incapable of performing the task it was designed for, it has failed. Failure could be structural (deep structure rutting, alligator cracking, longitudinal or transverse cracks in slabs, etc.) or functional (surface rutting, roughness, loss of skid resistance, etc.). This makes it imperative to study the behavior and performance of each component pavement layer under traffic (from accelerated pavement testing and field studies) and under varied climatic conditions. Proper material characterization for each layer is a must.

Constructing and maintaining a structurally and functionally sound pavement requires adherence to FAA standards and practices pertaining to pavement thickness design, material selection, construction, inspection, and maintenance. The FAA's standard related to pavement materials and construction is Advisory Circular (AC) 150/5370-10, Standards for Specifying Construction of Airports. Items covered in this AC include general provisions, earthwork, flexible base courses, rigid base courses, flexible surface courses, rigid pavement, miscellaneous, fencing, drainage, turfing, and lighting installation. If the standard is not followed, a pavement's full design life may not be realized. *Interaction and proper application of the pavement materials and construction and pavement thickness design standards can have a significant impact on pavement life*. The standards recognize that pavements fail for different reasons, e.g., deficiencies in performance related to structure, materials, construction, environment, or other.

Figure 3 shows a flow chart for a typical mechanistic-empirical pavement design procedure.

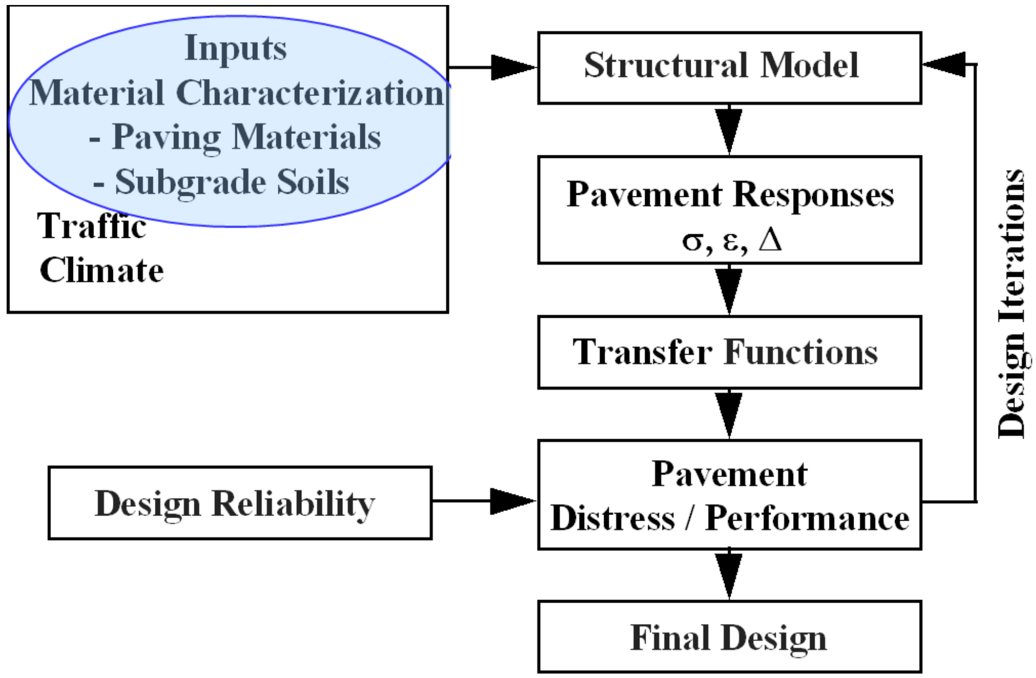

Figure 3. Mechanistic-Empirical Design Procedure

Any design procedure consists of a structural model (layered elastic or 3D FE model) into which material properties and traffic inputs, such as loading conditions, magnitude of loads, and number of repetitions, are provided to determine critical pavement responses that are then related to pavement life using empirical transfer functions. *No matter how sophisticated, accurate, and reliable the structural model is, the quality of output will depend on the quality and type of inputs provided.*

In the current FAA flexible pavement thickness design procedure, the only material property input required is the CBR of subgrade. Other inputs for material properties are fixed and cannot be changed by the user. Subgrade modulus is computed as E = 1500*CBR. No other mechanical property of unbound materials is used. Modulus is calculated internally as a function of layer thickness and subgrade CBR. If an airport pavement designer decides to use better quality material to improve pavement performance in terms of extending life, they cannot use the actual material properties and get benefit of reduced pavement thickness, and thereby is unable to justify the use of better quality materials. *Providing realistic material properties (such as HMA modulus at design temperatures, resilient modulus and shear strength of soils, and unbound materials) as inputs will improve the pavement life predictions.*

When designing pavements for a longer design life, greater thickness is not the only solution. One has to look at

- The most efficient use of materials to keep the project costs reasonable.
- Predicting pavement life becomes more critical.

- Research needs to be expanded so as to investigate alternate materials, construction techniques, greener technologies, and use of locally available materials (maybe with modifications).
- Performance related specifications (both for materials and construction).

New paving materials and modifications or improvements to conventional materials using nanotechnology are being developed on a regular basis. Before these materials could be placed in airport pavements, proper characterization of these materials is needed to study their performance under aircraft loads and durability under different environmental conditions.

The main objective of pavement materials research is to advance technology and tools for evaluation, testing, specification, mixture proportioning, and optimization for materials used in airport pavement construction, preservation, maintenance, and rehabilitation. Conventional materials, recycled materials, and new innovative/modified materials must be considered. The FAA's material testing laboratory is fully equipped and capable of performing the above-mentioned tests.

The main steps in this research program will include advanced characterization of pavement materials through the use of laboratory tests, insitu (field-testing projects), and full-scale accelerated pavement tests at the High Temperature Pavement Test Facility (HTPTF) and NAPTF. Data will be used to develop inputs for design procedures from the mechanical properties of materials (such as resilient modulus and shear strength). Also, the pavement material standards will be developed for newer materials and modified for conventional materials.

Table 1 lists the material properties and test procedures proposed for advanced pavement material characterization to develop inputs for FAARFIELD.

Table 1. Advanced Material Properties for Conventional Materials

MATERIALS	PROPERTY
Subgrade Soils	1. Shear strength 2. Resilient modulus 3. CBR
Base/Subbase materials [P-209, P-154]	1. Shear strength 2. Resilient modulus
HMA [P-401]	1. Dynamic modulus 2. Fatigue strength 3. Rut resistance 4. Static creep 5. Indirect tensile strength
Portland Cement Concrete [P-501]	1. Elastic modulus 2. Fatigue strength (endurance limit)

Comprehensive testing of in situ airport subgrade materials will be performed to develop improved criteria for subgrade characterization in FAARFIELD. Other properties of subgrade, such as Atterberg Limits, shear strength, and other properties, will be measured to identify those soil test properties (in addition to modulus) that strongly influence CBR. This will help develop the elasto-plastic FE model simulating the field CBR test.

New paving materials and modifications or improvements to conventional materials using additives are being developed on a regular basis. Before these materials can be placed in airport pavements, proper characterization of these materials is needed to study their performance under aircraft loads and durability under different environmental conditions. In addition to advanced material characterization, research will be initiated to characterize new sustainable, eco-friendly pavement materials so they can be incorporated into airport pavements.

Table 2 lists some of these materials along with the benefits and properties for characterizing them. Material properties will be determined using laboratory tests, and then performance models will be developed and verified using laboratory and full-scale tests at NAPTF and HTPTF.

Table 2. Sustainable Materials–Benefits and Material Properties

MATERIALS	BENEFITS	MATERIAL PROPERTIES
Polymer Modified Asphalt/ Binders	1. Better performance at wide range of pavement temperatures. 2. Improved resistance to thermal cracking at low temperatures. 3. Improved resistance to rutting at high temperatures.	1. Dynamic modulus 2. Fatigue strength 3. Rut resistance 4. Static creep 5. Performance under full-scale tests 6. Indirect tensile strength
WMA	1. Environmentally friendly. 2. Used at airports in USA and Europe but there is a lack of performance data. 3. Recommended by REDAC that FAA study WMA.	1. Dynamic modulus 2. Fatigue strength 3. Rut resistance 4. Static creep 5. Performance under full-scale tests 6. Indirect tensile strength
Geosynthetics, Geogrids, and Geotextiles – Used for -reinforcing base/subbase layers, - separation layer	1. Will allow use of marginal materials locally available. 2. Efficient way of improving pavement strength. 3. Type of subbase failures observed in CC1 and	1. Shear strength of unbound materials with and without geosynthetics, geogrids, and geotextiles. 2. Deflection response using heavy weight deflectometer (HWD) and performance using NAPTF/HTPTF.

- drainage layer	CC3 can be prevented. 4. New proven technology that is gaining widespread acceptance in construction industry. 5. Economical.	
Recycled Asphalt Pavement (RAP) as base/subbase material	1. Environmentally friendly. 2. RAP is not a biodegradable material and huge stockpiles exist. It is currently used in HMA but the amount of RAP used is limited. Use of RAP as base material will allow for large quantities to be used. 3. Pavement performance data exists for highway-type loading but no data exists under aircraft-type loading. 4. Economical.	1. Resilient modulus. 2. Shear strength 3. Deflection response using HWD and performance using HTPTF/NAPTF.

Material performance models will be developed using laboratory and in situ field tests. These models will then be verified, refined, or modified using results from full-scale tests performed at NAPTF and HTPTF. The results from this study will be used to develop updated guidelines and standards or specifications for airport pavement materials and their characterization. A material properties database will be created for use in PAVEAIR and LCCAs. Inputs for FAARFIELD will be developed based on mechanical properties of materials (such as resilient modulus and shear strength). New standards, specifications, and guidelines will be developed for new sustainable and eco-friendly paving materials.

Milestone Chart: Advanced Characterization of Paving Materials

Milestone	**FY**									
	13	14	15	16	17	18	19	20	21	22
Advanced Characterization of Pavement Materials in Laboratory, Field, HTPTF & NAPTF	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**		
Developing Material Properties Input for use in Design Procedure	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	
Developing/Modifying Pavement Material Standards/Specifications	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	

Cost Chart: Advanced Characterization of Paving Materials

Cost by Fiscal Year ($1,000)	13	14	15	16	17	18	19	20	21	22	TOTAL
Advanced Characterization of Pavement Materials in Laboratory, Field, HTPTF & NAPTF	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	0		16,000
Developing Material Properties Input for use in Design Procedure	200	200	300	300	300	300	400	500	500		3,00
Developing/Modifying Pavement Material Standards/Specifications	200	200	200	200	300	300	500	500	600		3,00
Advanced Characterization of Paving Materials Cost Summary	2,400	2,400	2,500	2,500	2,600	2,600	2,900	3,000	1,100		22,000

Materials Project No. 2:
Use of Additives and Nanoparticles to Improve Performance of Airport Pavement Materials

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2021
Estimated Cost for 8 Years: $5M

WHY NEEDED:

There is an absence of guidance on the use of newer material technologies. Locally available materials, which may not meet FAA material specifications, may be modified using nanoparticles or other modifiers to be made suitable for use in airport pavements. This would reduce or remove the requirement of hauling good quality materials from far away locations, thereby reducing construction costs and greenhouse gases. Providing realistic material properties, such as resilient modulus, shear strength, and others, for these new material technologies as inputs will improve the FAARFIELD and pavement life predictions.

OUTPUT OF RESEARCH:

The output from the use of additives will be new additions to the FAA standards and specifications for construction of airport pavements. The research will provide guidelines for material input properties, such as resilient modulus and shear strength, for use in FAARFIELD. The research results will be used to develop the paving materials property database for use in PAVEAIR and LCCAs. This research will result in increased use of locally available materials (materials modified with admixtures), quantifying material properties, improved/optimized pavement thickness designs, and more durable long-life airport pavements. This will help to save money through lower costs of initial construction, maintenance, and repairs as well as through lower user delay costs, conserve airport development funds, reduced downtime of runways, and improved ride quality and safety.

RATIONAL:

New paving materials and modifications or improvements to substandard materials using additives or nanoparticles are being developed on a regular basis. Before these materials could be placed in airport pavements, proper characterization of these materials is needed to study their performance under aircraft loads and durability under different environmental conditions. Use of clays in asphalt binders to improve response and performance under aircraft wheel loads will be studied at high pavement temperatures in the HTPTF. Nano-particles have been used in concrete to improve workability without increasing water-cement ratio and to increase concrete strength. However, performance data of these materials under aircraft loading is not available. Laboratory and full-scale tests at NAPTF and HTPTF will be used to study the performance of these materials and develop guidelines and specifications for future use on airport pavements.

Milestone Chart: Use of Additives and Nanoparticles to Improve Performance of Airport Pavement Materials

Milestone	FY									
	13	14	15	16	17	18	19	20	21	22
Evaluating the use of Additives and Nanoparticles for Improved Performance of Airport Pavement Materials	x	x	x	x	x	x	x			
Developing Standards/Specifications and Guidelines for Pavement Materials that have been modified with Nanoparticles and other Additives.					x	x	x	x	x	

Cost Chart: Use of Additives and Nanoparticles to Improve Performance of Airport Pavement Materials

Cost by Fiscal Year ($1,000)	13	14	15	16	17	18	19	20	21	22	TOTAL
Evaluating the use of Additives and Nanoparticles for Improved Performance of Airport Pavement Materials	200	400	500	750	750	750	750	0	0		4,100
Developing Standards/Specifications and Guidelines for Pavement Materials that have been modified with Nanoparticles and other Additives.	0	0	0	0	100	100	100	300	300		900
Evaluating Use of Additives and Nanoparticles for Improving the Performance of Airport Pavement Materials Cost Summary	200	400	500	750	850	850	850	300	300		5,000

Materials Project No. 3: Use of Data and Results From Airport Pavement Instrumentation and Field Testing Studies

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2021
Estimated Cost for 8 Years: $15M

WHY NEEDED:

In situ, as constructed characterization of pavement layers, is very critical for pavement life predictions. Characterization of in situ pavement layers is also very important for pavement management systems such as PAVEAIR in order to better predict pavement performance and improve planning for pavement rehabilitation, as well as to develop rehabilitation strategies. Pavement instrumentation data helps to better understand pavement system responses under varied climatic and operating conditions and the validation of analytical response prediction models. Airports in different regions experience different pavement distresses/failures modes. The NAPTF (indoor test facility) is unable to simulate these different climatic field conditions and thereby warrants field projects in different climatic regions. Also, there is a need to develop new instrumentation techniques based on nanotechnology, such as carbon nanotubes, microelectromechanical systems (MEMS), and fiber optics to measure pavement responses.

OUTPUT OF RESEARCH:

This research will result in new test procedures and techniques to characterize resilient modulus and shear strength of in situ pavement materials and layers. Guidelines for material input properties for use in FAARFIELD based on in situ material tests will be developed. The data will be used to develop an as-constructed pavement properties database for use in FAAPAVEAIR and the standardization of LCCAs. This study will provide better understanding of pavement behavior and responses, such as curling, thermal gradients, and strains, under different climatic conditions and will help to improve FAARFIELD and result in improved and optimized pavement thickness designs and more durable long-life airport pavements.

RATIONAL:

Laboratory testing results on pavement materials provides inputs for pavement design. However, the properties in the field can be very different because of construction techniques and other in situ conditions. Therefore, determination of in situ material properties through testing is very important to predict pavement life. These in situ tests must be simple, quick, and yet measure index properties of subgrade soils and unbound materials. These properties could include shear strength, resilient modulus, moisture content, density, and others. The application potential of in situ testing equipment, such as light weight deflectometer (LWD), vane shear, portable seismic property analyzer (PSPA), dirt seismic property analyzer (DSPA), and others to be determined, must be studied for different materials under different conditions. Correlations can then be developed between different material properties. Currently, the tests used for construction and acceptance are time-consuming. NDT procedures will be developed to expedite construction and also for quality control and quality assurance purposes. The application potential of testing equipment, such as PSPA, DSPA, and vane shear, has already been demonstrated at NAPTF. The procedures could be streamlined and standards developed with additional testing at NAPTF and also under field conditions.

Full-scale testing at NAPTF, which is an indoor facility, has concentrated on load-related effects on pavement failure. Environmental factors, coupled with traffic loads, play a significant role on pavement performance. The field instrumentation study was started by the FAA to collect pavement response and performance data under varied climatic conditions. Using results from these studies will improve FAARFIELD by including climatic effects on pavement behavior, such as slab curling and thermal gradients in HMA pavements, to name a few.

Pavement instrumentation data helps to better understand the pavement system responses and can be used for the validation and calibration of analytical response prediction models. The FAA has initiated field instrumentation and testing projects with the main objectives of (1) better understanding the long-term pavement behavior under varied climatic and operating conditions and (2) improved in situ characterization of paving materials. Improved pavement design and evaluation tools will conserve airport development funds and reduce the downtime of airfield pavements for construction and maintenance activities. The field instrumentation and testing projects will

- evaluate the effects of environment on pavement performance.
- determine thermal gradients within asphalt and concrete layers.
- determine the effects of material properties and variability on pavement response and performance.
- determine the effects of construction quality on pavement response and performance.
- determine the effects of specific design features on pavement response and performance.
- develop improved material characterization through in situ and laboratory testing at new construction projects and, when available, subgrade testing for rehabilitation projects.

In mechanistic-empirical design procedures, pavement responses, such as stresses and strains, are related to pavement life through the use of transfer functions. Generally, the pavement test sections in full-scale tests are instrumented to measure critical pavement responses. Pavement instrumentation data helps in a better understanding of pavement system responses and can also be used for the validation of analytical response prediction models. Attempts will be made to improve and develop new instrumentation techniques. The application potential of nanotechnology, such as MEMS, will be studied.

Milestone Chart: Use of Data and Results From Airport Pavement Instrumentation and Field Testing Studies

Milestone	FY 13	14	15	16	17	18	19	20	21	22
Developing New Test Procedures and Techniques to Characterize In Situ Pavement Materials and Layers	x	x	x	x	x	x	x	x		
Developing Guidelines for Material Input Properties for Thickness Design	x	x	x	x	x	x	x	x	x	
Evaluating In-use Pavement Load and Environmental Response Characteristics	x	x	x	x	x	x	x	x		
Developing Material Properties Database for use in PAVEAIR and LCCA		x	x	x	x	x	x	x	x	

Cost Chart: Use of Data and Results From Airport Pavement Instrumentation and Field Testing Studies

Cost by Fiscal Year ($1,000)	13	14	15	16	17	18	19	20	21	22	TOTAL
Developing New Test Procedures and Techniques to Characterize In Situ Pavement Materials and Layers	500	500	500	500	500	500	500	500	0		4,000
Developing Guidelines for Material Input Properties for Thickness Design	100	200	200	200	200	200	300	300	300		2,000
Evaluating In-use Pavement Load And Environmental Response Characteristics	700	700	800	800	1,000	1,100	1,200	1,200	0		7,500
Developing Material Properties Database for use in PAVEAIR and LCCA	100	100	100	200	200	200	200	200	200		1,500
Airport Pavement Instrumentation and Field Testing Cost Summary	1,400	1,500	1,600	1,700	1,900	2,000	2,200	2,200	500		15,000

PAVEMENT MATERIALS R&D TEAM SUMMARY

Consequences of not doing R&D in Pavement Materials:

1. Increased downtime of runways (for construction/maintenance/repairs)
2. Increased construction costs
3. Increase in user-delay costs
4. Loss of revenue
5. Increase in maintenance and rehabilitation (M&R) costs

Benefits:

1. Saving millions of dollars through lower costs of initial construction maintenance/repairs as well as through lower user-delay costs
2. More durable long-life airport pavements
3. Better understanding of pavement materials
4. Improved/optimized pavement thickness designs
5. Conserve airport development funds
6. Reduced downtime of runways
7. Improved ride quality
8. Increased use of environmentally friendly (greener) materials
9. Improved safety
10. Increase in revenue
11. Increase in passengers
12. Decrease in greenhouse gases

Airport Pavement Materials R&D Projects:
Estimated Total Cost - $42 Million

Airport Pavement Evaluation R&D Team

Evaluation Project No. 1:
Improvements to FAA Airport Pavement Software Programs

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2022
Estimated Cost for 9 Years: $14.5M

WHY NEEDED:

Over the last 10 years, the FAA has developed the following airport pavement software programs: FAA PAVEAIR, COMFAA, BAKFAA, FAARFIELD, and ProFAA. Continually updating these software programs will ensure the applications function properly as programming environments change and preserve agreement with applicable advisory circulars. This initiative includes the proposal to create Data Warehouses (DW) to develop data storage repositories and a logical system for airport pavement data retrieval and analysis. This data will be required to allow pavement engineers to access airport pavement data, such as pavement inspections, pavement construction and maintenance history, and traffic, for use as a guide for pavement design and maintenance requirements. This project will also help evaluate the feasibility of developing methodologies to double the expected life of large-hub runway construction from 20 to 40 years.

OUTPUT OF RESEARCH:

The continual evaluation of FAA software programs will ensure the programs remain current with changes to Information Technology practices. The creation of the database warehouse will enable the FAA to become the primary holder of information for civil airports in the U.S.. The DW will provide detailed airport pavement data in more detail and in a searchable and analytic way. Users can use the data to predict their future pavement condition and likely repairs and costs based on the history of similar pavements.

RATIONALE:

Proposed advances in the FAA airport pavement evaluation program, FAA PAVEAIR, will be comprised of several initiatives. The common benefit to pavement design and pavement materials is the potential for databases that will provide pavement performance history with respect to traffic loading and climate. These databases will provide pavement engineers with a national airport pavement registry to assess how pavements constructed of specific thickness and materials and exposed to known climate and traffic loads performed over the life of the pavement. The successful population of these databases is a critical milestone for the study of increasing pavement life from 20 to 40 years. The initiatives are as follows.

a. **AIP Project Repository.**
All of these efforts share a common principal; an existing body of knowledge for airport pavement does not exist. For the AIP Project Repository, this data probably exists at individual airports or regions, but it has not been organized in a way that could be useful to pavement engineers. The same is true for the traffic and climate data, this data can be found at any airport of significant size; however, the knowledge exists as separate entities. This effort will collect that data from various sources and locations to provide pavement engineers with one resource for pavement design, pavements materials, and pavement maintenance and repair. The determination of the information to be collected is a significant first step for this effort.

b. **Data Warehouses.**
The creation and use of DWs are a critical component of the data to be acquired through the 40-year pavement life project and the AIP Project Repository initiative. DWs are databases used for reporting, data mining, and data analysis. DW stores current and historical data and is used to collect information from various sources and make it beneficial to users. As an example, the most discussed proposed use of a DW is the creation and population of a database using actual pavement histories from airports to develop models for pavement deterioration curves. Future refinements for pavement deterioration curves include the addition of traffic and climate parameters into the curve calculations. The more databases that these curves can draw from, the more confidence users can have in their accuracy.

The development of several DWs is anticipated, and a great deal of analysis will be required to select the data to be input to ensure users can generate their required output. A number of choices will be necessary for the development, such as selecting the data to be filtered, designing the access layers for storage of raw data, and determining the degree and extent of integrating the DW with other data (i.e., foreign object debris (FOD), friction, etc.) or existing FAA pavement software programs.

c. **(LCCA Database, LCCA Procedures, Database Structure Optimization.**
As defined by the FAA, “Life cycle costs are defined to encompass the entire period facilities or equipment progress through a budget, including the stages for the airport planning, construction, commission, operating, management, maintenance, repair, improvements, and activities decommissioning the project.” LCCA also incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments. Finally, LCCA attempts to identify the best value for investment expenditures. The improvement of the LCCA model in FAA PAVEAIR, AirCost, is an early step in the incorporation of LCCA into pavement design and materials. As LCCA matures and the FAA improves its understanding and benefits of LCCA, it will be evaluated as a tool to be added to other FAA software programs, such as FAARFIELD. The pavement engineer may have the future ability to evaluate the pavement construction and maintenance costs over the life of the pavement as part of the initial pavement design. As a result, pavement engineers will have an LCCA airport pavement standard to be used for all phases of pavement life. Another product would defining a standard on how airport pavement engineers can use LCCA that can then be included into an advisory circular.

d. **Improvements to FAA Software Programs.**
As mentioned, the FAA currently offers five free software programs: (1) BAKFAA to backcalculate pavement modulus using H/FWD deflections; (2) FAARFIELD for the thickness design of asphalt and concrete pavements; (3) ProFAA for computing pavement elevation profile roughness indexes; (4) COMFAA, which calculates ACN and PCN based on traffic loading and pavement structure; and (5) FAA PAVEAIR–a web-based airport pavement management system. This task proposes the following improvements to FAA pavement software programs.

i. Incorporate Artificial Intelligence (AI) into FAA Software Programs.
The common benefits of AI to pavement design and pavement materials for the software programs enhancement are the capability to collect human knowledge and apply this learning to reason through problem solving without reprograming source code. In many fields, certainly pavements, data are being collected at prolific rates. To extract useful knowledge from the rapidly growing volumes of data, using computational theories and tools is necessary. The process of extracting knowledge from data is called knowledge discovery. Different tools are used for mining data to discover knowledge, but the newest generation of tools comes from the field of AI. AI-based tools attempt to mimic human intelligence. Because of their ability to solve complex problems, they are rapidly replacing the classical statistical tools developed in the past. On a technical level, the techniques and algorithms that can learn from data are characterized as intelligent. The human capability of learning, generalizing, memorizing, and predicting is the foundation of any AI system. Knowledge discovery is the process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data. This is particularly valuable for typical engineering functions using iterative evaluation of large data sets such as pavement design and pavement modulus backcalculation.

ii. Incorporate Global Positioning System (GPS) Capabilities into Existing FAA Software Programs.
Incorporating GPS into FAA software programs will provide users with accurate locations of where the data was acquired in the field. This is anticipated to provide immediate value for programs that are used to acquire data in the field, such as FAA PAVEAIR, BAKFAA, and ProFAA. The use of an accurate GPS for vertical measurements is also being researched for inclusion in the FAA NDT van pavement-imaging data acquisition system. Adoption of this system could be incorporated in future versions of ProFAA.

iii. Integration of FAA Airport Pavement Software.
Integration of FAA PAVEAIR and other FAA software programs will require a common platform for the applications to communicate with each other. The analysis for this integration has begun. Combined with the pavement repository, this effort will create a suite of pavement software programs for users to evaluate and design airport pavements, incorporating predictive modeling based on traffic, climate, construction, and maintenance histories. The integration of design and evaluation software as a web-based program will be the future result of this initiative. The

integration of the software programs will allow FAA PAVEAIR to send and receive data from the FAA and then initiate the operation of other programs for pavement evaluation and design. A critical step is to convert all external data files to Extensible markup Language (XML) for compatibility between all pavement software programs.

Milestone Chart: Improvements to FAA Airport Pavement Software Programs

Milestone	FY									
	13	14	15	16	17	18	19	20	21	22
Database of Materials and Construction Costs – AIP Project Repository	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	
LCCA Database, LCCA Procedures, Structure Optimization	**x**	**x**	**x**	**x**	**x**	**x**	**x**			
Integrate Design and Evaluation Software as Web-Based Application	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**		
Incorporate Artificial Intelligence Into FAA Applications		**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Incorporate GPS Into Existing FAA Programs		**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	
Integrate FAA PAVEAIR With Other ANG-E262 Software Programs		**x**	**x**	**x**	**x**	**x**				

Cost Chart: Improvements to FAA Airport Pavement Software Programs

Cost by Fiscal Year ($M)	13	14	15	16	17	18	19	20	21	22	TOTAL
Database of Materials and Construction Costs – AIP Project Repository	250	250	500	1,000	1,000	250	250	250	250	0	4,000
LCCA Database, LCCA Procedures, Structure Optimization	100	500	500	100	100	100	100	0	0	0	1,500
Integrate design and evaluation software as web-based application	500	500	500	500	500	500	500	500	0	0	4,00
Incorporate Artificial Intelligence into FAA Applications	100	100	200	500	500	250	250	250	250	100	2,500
Incorporate GPS Into Existing FAA Applications	0	200	200	200	200	200	200	200	100	0	1,500
Integrate FAA PAVEAIR With Other ANG-E262 Software Programs	0	200	200	200	200	200	0	0	0	0	1,000
Improvements to FAA Airport Pavement Software Programs Cost Summary	950	1,750	2,100	2,500	2,500	1,500	1,300	1,200	600	100	14,500

Evaluation Project No. 2:

Development of New Roughness Standards for In-Service Airport Pavement

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2022
Estimated Cost for 9 Years: $11.0M

WHY NEEDED:

Pavement roughness has been used for evaluating functional pavement conditions. Multiple indexes have been developed and used, including International Roughness Index (IRI), to quantify the conditions. FAA AC limits maximum deviations by straightedge measurements only for new constructed or overlay pavements. IRI is currently the most popular roughness index in highway pavement evaluations, but the index is not an appropriate index for airfields since the aircraft pavement characteristics, loading conditions, dynamic movements responding to the pavement surface, and human factors are very different from highway traffic conditions.

Recently, both the International Civil Aviation Organization (ICAO) and the FAA adopted the Boeing Bump Index (BBI) to evaluate an in-service airport pavement roughness index. The BBI was initially developed considering the fatigue damage of aircraft gears without considering pavement functional life and rideability during landing or takeoff.

The roughness standard for in-service airport pavement will be used to determine maintenance and/or requirements. Determination of roughness maintenance requirements in a Pavement Management System (PMS) is critical because it will effect pavement serviceability and budget decisions.

OUTPUT OF RESEARCH:

None of the current roughness indexes were tested or examined to fulfill the evaluation of in-service airfield pavements functional conditions. This is related to pavement serviceability for pilots, and passengers' roughness research needs to develop indexes for functional life at in-service airfield pavements.

This project will quantify the concerns to the pavement users and airplane manufacturers in terms of survey data from pilots and current BBI computations on given airport profiles.

Roughness data for the new standard will be stored in the FAA's database in conjunction with currently available data as part of PMS and used for pavement design with further analysis.

RATIONALE:

The following projects comprise this task.

a. **Comparison of Full-Scale Aircraft Response With Simulator Response and Ride Quality Criteria in Simulator Studies – Expand to Airbus Simulator and Instrument Boeing 747.**
Currently available roughness indexes will be reviewed and compared with aircraft simulation results from the FAA's current Boeing 737 simulator project. Relationships will be found between outputs from the simulator and current indexes followed by developing linear or nonlinear correlation models. The outputs from the simulator will be subjective rating, showing pavement serviceability and measured responses. The sensitivity analysis and correlation coefficients of independent parameters in the model will be determined. The results will provide ride quality criteria. This project will expand the research scope to the Airbus simulator and to an instrumented Boeing 747.

b. **Statistical Analysis to Establish a Limit for Pavement Serviceability.**
Statistical analysis will be performed to reflect in-service airfield pavement conditions to setup lower or upper limits of roughness indexes. Profile data collected from different airport categories will be processed for index computations. The distribution of each index will be plotted and analyzed to determine the lower or upper limits, considering the simulator results and pavement conditions in-service.

Milestone Chart: Development of New Roughness Standards for In-Service Airport Pavement

Milestone	FY									
	13	14	15	16	17	18	19	20	21	22
Comparison/Reviews of Current Roughness Indexes and Standards	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	
Comparison of Full-Scale Aircraft Response With Simulator Response		**x**	**x**	**x**	**x**	**x**	**x**	**x**		
Statistical Analysis to Setup a Limit for Pavement Serviceability						**x**	**x**	**x**	**x**	**x**
Ride Quality Criteria in Simulator Studies – Expand to Airbus Simulator and Instrumented Boeing 747		**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**

Cost Chart: Development of New Roughness Standards for In-Service Airport Pavement

Cost by Fiscal Year ($1,000)	13	14	15	16	17	18	19	20	21	22	TOTAL
Comparison/Reviews Of Current Roughness Indexes And Standards	200	200	250	250	250	250	250	250	100	0	2,000
Comparison Of Full-Scale Aircraft Response With Simulator Response	0	500	500	500	500	500	500	500	0	0	3,500
Statistical Analysis to Setup a Limit for Pavement Serviceability.	0	0	0	0	0	200	200	200	200	200	1,000
Ride Quality Criteria in Simulator Studies – Expand to Airbus Simulator and Instrumented Boeing 747	0	500	500	500	500	500	500	500	500	500	4,500
Development of New Roughness Standards for In-Service Airport Pavement Cost Summary	200	1,200	1,250	1,250	1,250	1,450	1,450	1,450	800	700	11,000

Evaluation Project No. 3:

Pavement Surface Profile Data Collection, Processing, and Analysis

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2019
Estimated Cost for 7 Years: $3.0M

WHY NEEDED:

Computed roughness indexes are not only for evaluating in-service pavement conditions but for assuring the quality of newly constructed pavements. The roughness index indicating pavement surface conditions is computed after processing the collected longitudinal pavement surface profiles. Therefore, the details of measurement methods, processing, and analysis need to be improved to reflect airfield pavement conditions better in current FAA ACs.

The other ACs describe construction quality control using straightedge and California profilograph and requirements to meet geometric gradients. The measurements, processing, and analysis of the collected longitudinal and transverse profiles for construction quality control and safety will be standardized to provide repeatability and reproducibility for pavement surface conditions evaluations.

Longitudinal profile data need to be collected and analyzed to design extended pavement life from 20 to 40 years by evaluating in-service pavement conditions of different pavement types and ages. The profile data will be stored in an FAA database with other evaluation data for further analysis.

OUTPUT OF RESEARCH:

Current or new criteria to develop standard procedures for roughness profile measurement, processing, and analysis will be established. Correlations with different profiling devices and their characterizations will be included while the standard procedures are developed. Comparisons of data collection and processing between airfield and highway will be conducted. Also, the profiles from grooved areas in the collected runway profiles will be characterized to further develop automated pavement groove evaluation software.

This research for geometric gradients and sight distance on the runway will be reviewed and modified for inclusion into ACs as necessary. Runway intersection grading criteria will be developed based on the collected longitudinal and transverse profiles.

The new design method for 40-year pavement life will use the collected runway profile data to monitor pavement surface conditions corresponding to pavement ages with 20-year life pavement design.

RATIONALE:

The following projects comprise this task.

a. **Runway Profile Data Collection and Analysis.**
Longitudinal profiles from in-service airport pavements will be collected at the airports in multiple categories, such as large-hub, medium-hub, and small-hub airports. Different types of profiling devices will be used on flexible and rigid pavements with different pavement ages. The collected profile data will be used for 40-year life pavement design and device comparisons by measurement and procedures. The current 20-year life pavement design will be evaluated using the collected profiles to quantify the pavement conditions to extend the pavement life. The details of airport selections, device selections, and procedures will be determined based on specific objectives for each task. Walking profiler, inertial profiler, 6th order Butterworth filter, highway

b. **Runway Intersection Grading Criteria.**
Safety needs to be evaluated at the runway intersection as well as ride quality when any rehabilitation activities are required. There will be two projects related to this effort: (1) runway intersection grading criteria and (2) automated groove inspection software. Since drainage is a primary concern when maintenance or rehabilitation is required, some alternatives would be considered, such as placing a porous asphalt layer or improving grooves. New large aircraft with different gear configurations and longitudinal profiles that consider vertical sight distance will be collected and analyzed.

c. **Automated Groove Inspection Software (ProGroove).**
The improvements of grooving can be accomplished by geometric changes with appropriate time and methods of maintenance and rehabilitation. Airport pavement grooves for in-service airfield pavement will be monitored using the FAA's groove detection software ProGroove. The results will be used to establish automatic groove condition parameters in ProGroove. Statistical analysis will be performed to reflect in-service airfield pavement conditions to setup lower or upper limits of grooving serviceability.

Milestone Chart: Pavement Surface Profile Data Collection, Processing, and Analysis

Milestone	FY									
	13	14	15	16	17	18	19	20	21	22
Runway Profile Data Collection and Analysis	**x**	**x**	**x**	**x**	**x**					
Automated Groove Inspection Software		**x**	**x**	**x**	**x**	**x**				
Runway Intersection Grading Criteria			**x**	**x**	**x**	**x**	**x**			

Cost Chart: Pavement Surface Profile Data Collection, Processing, and Analysis

Cost by Fiscal Year ($1,000)	13	14	15	16	17	18	19	20	21	22	TOTAL
Runway Profile Data Collection and Analysis	200	200	200	200	200	0	0				1,000
Automated Groove Inspection Software	0	200	200	200	200	200	0				1,000
Runway Intersection Grading Criteria	0	0	200	200	200	200	200				1,000
Development of New Roughness Standards for In-Service Airport Pavement Cost Summary	200	400	600	600	600	400	200				3,000

Evaluation Project No. 4:
Nondestructive Pavement Testing

Estimated Project Start Date: FY 2013
Estimated Project Completion Date: FY 2022
Estimated Cost for 9 Years: $23.5M

WHY NEEDED:

Nondestructive airport pavement testing is the hub of airport pavement evaluation. The projected enplanements predicted by the FAA Next Generation Air Transportation System (NextGen) initiative require the efficient use of the time given by airports for pavement evaluation. The FAA forecast predicts that the industry will grow from 731 million passengers in 2011 to 1.2 billion in 2032. Because of this, airport pavements will need to be evaluated faster and more efficiently. The results, when delivered to airport managers for maintenance and repair decisions, must be comprehensive and rational. NDT pavement testing will also have an increasing role in construction quality control and quantity acceptance for construction or repair of pavement projects. In addition, new large aircraft with different gear configurations and increasing flight frequency require more efficient and accurate pavement evaluations to reduce direct and indirect costs caused by any delays.

OUTPUT OF RESEARCH:

More accurate data with less collection time and manpower from an in-service airport pavement surface would be required to determine maintenance and rehabilitation strategies. Automated PCI are immediate and calculable: Currently, the PCI is the dominant index to evaluate pavement surface conditions, and for any given pavement, requires a visual survey that may require a month of time and many labor hours to develop for a given pavement. The same end product when using a mobile imaging system drastically reduced the time to collect the data (reduction of disruption of airport operation) and the time to process the data. NDT technologies would fulfill the need for a better monitoring system for mechanistic and chemical pavement behaviors. The application would be for aggregates in unbounded layers for a more reliable and faster standard. Safety issues in the airport will be improved by reducing the accident rate and indirect costs, such as passenger delay time and airport operation costs.

RATIONALE:

The following projects comprise this task.

a. **Investigate and Evaluate New and Current NDT Technologies for Airport Pavements.**
   Applications of new technologies and re-evaluation of current NDT for airport pavement conditions will lead to reduced runway closures and FOD: The most widely used NDT device for pavement structural evaluation is the Falling/Heavy Weight Deflectometer F/HWD. The F/HWD test and data analysis will be established to reflect airplane traffic conditions, considering pulse width. The continuous deflection profiles provided by Rolling Dynamic Deflectometer (RDD) and the thickness estimations by GPR would be used in conjunction with F/HWD.

b. **Evaluation of NDT Applications Using the NDT Vehicle.**
The use of NDT proposes to improve the quality of pavement evaluation in less time with less manpower. Using a vehicle-mounted pavement imaging platform similar to the NDT van, it is anticipated that, in the future, pavement evaluations (for example a runway) will be accomplished in 3 or 4 hours versus a 3- or 4-day effort if evaluated visually on foot. Another advantage of the mobile NDT platform is that decisions will be made with complete and accurate data. An airport owner will base maintenance and repair strategies on a sampled evaluation of a given runway or taxiway. This can lead to construction activities that are not effective across the entire airport system and can attribute to ineffective use of funds by providing inappropriate or unneeded maintenance and repair. System wide data provides airport owners with an assessment of the needed repair and maintenance of the entire branch or network, which improves how funds are spent because the correct solutions are chosen from the onset of a project, focusing the funds where it is needed most. The final advantage is time. In support of the FAA NextGen program, the NDT vehicle can perform more tests on a pavement in less time, which reduces pavement closures. With NextGen projecting increased operations at airports, it is necessary to reduce pavement closures. By collecting data quicker and providing systemwide data, a mobile NDT platform supports this goal.

c. **Creation of an Automated PCI With Pavement Imaging Technology.**
With automated PCI, another step in the process of developing a distress survey is eliminated. A data collection team will be able to image a pavement over the course of one day, download the data to a PC to process, and the computer will derive the PCI from the images collected. This will create the potential to survey and develop a PCI report within two days' time. The development of automated PCI is the most aggressive and technically challenging effort for the pavement evaluation R&D team. There are a number of identified imaging and programming issues to be resolved.

d. **Application of Nanotechnologies for NAPTF and In-Service Airport Pavements.**
Nanotechnologies will be applied to characterize mechanistic pavement responses to the airfield traffic. The application would focus on aggregates in unbounded layers for more reliable and faster analysis time. Nanotechnologies It will be used to monitor chemical responses of pavement materials like, Alkali-Silica Reaction (ASR), which is dependent on environmental conditions. The ASR study will be involved in fundamental research into the chemical and physical processes that cause ASR gel damage.

e. **Characterizations of Airfield Pavement Texture Including Evaluation of Current Friction Measurement Technologies.**
Multiple devices, which are used to measure pavement texture, will be re-evaluated and compared to each other to characterize skid resistances and airfield traffic conditions. A Circular Texture Meter is a friction device that measures microtexture, corresponding to ASTM E2157. The device measures pavement microtexture using a rotating laser displacement sensor. This device collects coefficient of friction measurements ranging from free-rolling to fully-locked conditions, whereas other devices, like the British Pendulum Tester (BPT), measure data at a discrete point of breaking condition.

One of the unique aspects of NDT for pavements is that the technologies being used were often developed for other purposes. Advancements in ultrasonic tomography, MRI, and two-dimensional (2D) and 3D surface imaging have led the FAA to begin investigating these technologies. Other known new technologies that will be evaluated in the coming decade are Light Detection and Ranging (LIDAR), Traffic Speed Deflectometer (TSD) or Rolling Weight Deflectometer (RWD), and X-ray Computed Tomography (CT). To develop faster and more accurate methods of pavement evaluation, these and other new pavement evaluation technologies must be assessed. The following describe each new technology.

LIDAR is an optical remote-sensing technology that can measure the distance to, or other properties, of a target by illuminating the target with a light source, often using pulses from a laser. With recent advances in LIDAR, units have been installed on survey vehicles to measure and plot objects as a moving vehicle takes measurements. LIDAR has been used successfully in post-Katrina mapping in New Orleans. The pavement evaluation team envisions that it would have a potential application to map airport pavement, eventually to describe or assess pavement distresses.

The TSD or RWD, one of the newer tools available for managing asphalt pavements, is a device designed to measure pavement deflections while traveling at high speeds. This device was designed to provide deflection data that can be used as a relative measure of the structural capacity and stiffness of asphalt pavements. The data can be used to provide a structural map of an entire pavement network and to target areas for detailed inspection and testing using FWD, coring, or other static tests. With the RWD, an agency can concentrate resources on those areas most needing attention.

The RWD is constructed using a specially designed tractor-trailer to load the pavement and measure deflection responses. The tractor houses the operator, laser controls, and computer equipment for the device. The trailer is 53 feet long and is designed to control pitch and roll. The trailer has a single rear axle that is loaded to 18,000 lb. The equipment includes four high-precision laser-measuring devices that are mounted 8.5 feet apart with the rearmost laser placed between the rear wheels and just behind the centerline of the rear axle, see Figure 4.

Figure 4. RWD Tractor-Trailer and Placement of Laser-Measuring Devices

Considerations for Using TSD or RWD:

- Determine structural health of the whole system.
- Focus expensive testing to higher need areas.
- Simplify tracking of pavement performance.
- Limit exposure of personnel to hazardous traffic.
- Correlates with other devices.
- Little sensitivity to speed of collection.
- Useful only for flexible pavements, but research has begun on rigid pavements.
- Operates day or night but not in the rain.

X-ray Computed Tomography (CT) is used to capture the internal structure of asphalt mixtures. The x-ray CT images are analyzed using image analysis techniques. 3D maps of air void distribution in pavement sections are generated by inputting percent air voids as a function of depth (from x-ray CT images) and the location of cores in the pavement. This application is considered valuable because it provides an estimate of percent air voids at any point in the pavement section in every 1 mm of depth. As such, one can determine the detailed three-dimensional distribution of air voids. The uniformity of air void distribution is then quantified using mathematical indices. As an example of a proposed application for the FAA, cores can be scanned using x-ray CT to capture the air void distributions. The air void distribution can then be compared to target construction air void values. This technology provides a method for comparing compactability values of asphalt mixtures in the field with compactability values of asphalt mixtures in the laboratory. After the constructed pavement is opened, quantified air void changes with respect to aircraft traffic would be used for characterizing pavement performance represented by crack initiation and propagation, and plastic deformation

f. **Estimation of Remaining Airport Pavement Life.**
With the increasing sophistication of pavement evaluation tools, such as 2D and 3D pavement imaging, the concept of integrating stand-alone NDT technologies into a merged approach is possible.

Pavement-imaging software is anticipated to improve to the extent that pavement distresses can be identified, the distress dimensions quantified, and users will be able to evaluate an entire branch of a network (taxiway, runway, etc.) rather than sampling several unit areas. The image collection should take no more than 3 or 4 hours for a runway, and the airport owner could have the results of a 100% inspection in a matter of days. This is not automated PCI, but a pavement-imaging software capability that can automatically identify specific areas that require a closer visual inspection.

When air-coupled GPR and an inertial profiling system are added to the vehicle collecting pavement images, users will have additional data to be assimilated into the imaging data. For example, on an asphalt runway, if structural-related distresses, such as alligator cracking and rutting, are identified and located, F/HWD equipment can be focused on those areas. On concrete pavements, using an inertial profiler in conjunction with GPR and the pavement image evaluations can be used to identify and confirm structural-related distresses, such as longitudinal, transverse, and diagonal cracks or faulting. A distress analysis of the entire pavement branch can provide a more focused evaluation so the consultant or airport owner has an understanding of the entire pavement condition of a branch of the network rather than an extrapolated view based on sample units. This research will be focused on using existing stand-alone technologies and merging their capabilities to provide airport owners a rational estimate of remaining pavement life.

Visual evaluation will quantify surface distresses and suggest structural anomalies. HWD, for example, will quantify structural capacity but divulge nothing about the surface. The NDT technologies should be evaluated in relation to each other to determine the condition of the pavement through its entire cross section. Technologies such as pavement imaging, RDD, F/HWD, GPR, and x-ray CT must be evaluated for use individually and then, under the auspices of remaining pavement life, develop a procedure to use the technologies in combination to provide airport managers and pavement engineers a dependable method to assess the condition of the pavement from the surface to the subgrade. The other important purpose is to safely acquire accurate data in short periods to maximize the time allotted on the pavement.

The data and analysis for this work is anticipated to be provided in part by the 40-year pavement life project. This project will give the FAA the opportunity to collect profiling, imaging, visual evaluation, and F/HWD data at the same time and same location. This work will also use the traffic loading and climate feasibility study currently begun.

Milestone Chart: Nondestructive Pavement Testing

Milestone	**FY**									
	13	14	15	16	17	18	19	20	21	22
Evaluation of NDT applications in NDT vehicle		**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Automated Crack Detection/PCI Software		**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	
Evaluate NDT Technologies: LIDAR, RDD, and X-ray CT			**x**	**x**	**x**	**x**	**x**	**x**		
Estimation of Remaining Airport Pavement Life Using NDT Technologies	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**		
Develop New Applications and Procedures for Current Structural and Materials Evaluation	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Application of Nanotechnologies for NAPTF and In-Service Airport Pavements		**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Characterizations of Airfield Pavement Texture Including Evaluation of Current Friction Measurement Technologies	**x**	**x**	**x**	**x**	**x**	**x**				

Cost Chart: Nondestructive Pavement Testing

Cost by Fiscal Year ($M)	13	14	15	16	17	18	19	20	21	22	TOTAL
Evaluation of NDT applications in NDT vehicle	0	250	250	250	250	500	500	500	500	500	3,500
Automated Crack Detection/PCI Software	0	500	500	1,000	1,000	1,000	1,000	1,000	500	0	6,500
Evaluate NDT Technologies: LIDAR, RDD, and X-ray CT and Estimation of Remaining Airport Pavement Structural Life Using NDT	0	0	500	500	1,000	1,000	500	500	0	0	4,000
Develop New Applications and Procedures for Current Structural and Materials Evaluation	400	400	400	400	400	400	400	400	400	400	4,000
Estimation of Remaining Airport Pavement Life Using NDT Technologies	100	100	400	400	200	100	100	100	0	0	1,500
Application of Nanotechnologies for NAPTF and In-Service Airport Pavements	0	250	250	250	500	500	500	250	250	250	3,000
Characterizations of Airfield Pavement Texture Including Evaluation of Current Friction Measurement Technologies	100	200	200	200	200	100	0	0	0	0	1,000
Nondestructive Pavement Testing Cost Summary	600	1,700	2,500	3,000	3,550	3,600	3,000	2,750	1,650	1,150	23,500

PAVEMENT EVALUATION R&D TEAM SUMMARY

Consequences of not doing R&D in Pavement Evaluation:

1. Increased maintenance cost
2. Decreased efficiency of nationwide budget spending
3. Increased downtime of runways for inspection, maintenance, and repairs
4. Lack of support for Advisory Circulars

Benefits:

1. Effective budget allocations
2. Increased pilot and passenger satisfaction (rideability)
3. Decreased aircraft maintenance costs
4. Decreased accident rate
5. More accurate data reflecting airfield pavement conditions
6. Reduced runway downtime
7. Reduce indirect costs such as passenger delay time and airport operation costs
8. Support to AAS-100 for improvement or creation of Advisory Circulars

Airport Pavement Evaluation R&D Projects:
Estimated Total Cost - $52 Million